Розрахунок діаграми напружень матеріалу круглої труби на базі дослідів бокового стискання

Аббас Нікнеяд[1], Сеїд Алі Елагі[2]

Кафедра механічної інженерії, Факультет інженерії,
Університет Ясуджа, а/с: 75914-353, Ясоу, Іран,
[1] E-mail: Aniknejad@mail.yu.ac.ir
[2] E-mail: elahiseyyedali@gmail.com

Цікаво зазначити, що тонкостінні елементи, такі як пластини, каркаси та труби в автомобільних корпусах, фюзеляжах літаків і корпусах кораблів, характеризуються схожими співвідношеннями товщини і ширини. Ці корпусні деталі в основному піддаються стискаючим навантаженням під час удару, вони можуть зазнавати серйозних прогинів, які можуть перевищити товщину стінки на два порядки величини. Останнім часом досліджувалась значна кількість задач імпульсної інженерії, передусім по темі динамічної реакції корпусних деталей в зоні пластичності. Це сприяло кращому розумінню видів несправностей, а також моделей розсіювання енергії під час удару в таких деталях. Система поглинання енергії перетворює, повністю або частково, кінетичну енергію на іншу форму енергії. **У** цій роботі розглянуто систему поглинання енергії, при якій **е**нергія розсіюється завдяки пластичній деформації металевих поглиначів енергії. Деякі попередні теоретичні обгрунтування досліджувались експериментально. З цією метою проаналізовано характер пошкодженнь мідних труб з круглим поперечним перерізом при їх стисканні між двома твердими пластинами. Одне з попередніх рівнянь розраховує плече пари сил круглих труб під час процесу вирівнювання. Порівняння результатів експерименту з попередніми теоретичними розрахунками показує, що більш точно змогли теоретично розрахувати плече сили для круглих труб з більшою товщиною стінок і меншим діаметром. Два інші рівняння розраховують модуль пружності та межу текучості матеріалу труб на базі експериментальних даних досліду бокового стискання між двома твердими пластинами. Ці розрахунки застосовувалися для створення діаграм напружень матеріалу труб з використанням використовуючи результатів експерименту. Дослідження доводить, що збільшення товщини стінок та діаметру труб зменшує похибку.

Prediction of the stress-strain diagram of circular tube material based on lateral compression tests

Abbas Niknejad[1], Seyed Ali Elahi[2]

Mechanical Engineering Department, Faculty of Engineering,
Yasouj University, P.O. Box: 75914-353, Yasouj, Iran,
[1] E-mail: Aniknejad@mail.yu.ac.ir
[2] E-mail: elahiseyyedali@gmail.com

In this article, some previous theoretical relations are investigated, experimentally. For this purpose, collapse behavior of brazen tubes with circular cross-section, when compressed between two rigid plates, is examined. One of the previous equations predicts the produced moment arm of circular tubes during the flattening process. Comparison of the experimental results with the theoretical predictions shows that the theoretical relation calculated the produced moment arm of thicker circular tubes with smaller diameters with good correlation. Two other equations predict elastic modulus and yield stress of tubes material, based on the experimental data of lateral compression test between two rigid plates. These relations employed to sketch the stress-strain diagrams of tube material, using experimental results. The investigations conclude that increasing of wall-thickness and diameter of tubes causes decrement of errors

Keywords – Flattening, brazen tube, lateral compression, experimental investigation, circular tube.

I. Introduction

During the last two decades, metallic cellular structures have been developed and are growing in use as new engineering materials. These ultra-light metal materials possess unique mechanical properties, such as high specific rigidity and high impact energy absorption at low weight, suitable properties in all directions giving tolerance to varying direction of loading, and stable deformation mode and adaptation to loading condition during deformation [1]. Reddy and Reid [2] experimentally investigated phenomena associated with large deformation compression of metal tubes in flattening process. The lateral collapse load of aluminum and mild steel tubes with square and rectangular cross-sections were determined by Gupta and Khullar [3]. England and Gregory [4] considered the finite plane-strain deformations of an elastic-plastic tube laterally compressed between two rigid plates. Zeinoddini et al. [5] studied axially pre-loaded tubes that examined under lateral dynamic impact loads. Nemat-Alla [6] described reproducing hoop stress–strain behavior in tubular material using flattening tests. Calme et al. [7] investigated three-dimensional braided composite rings subjected to lateral compression force. A finite element model established to describe the damage in thin-walled tubes under lateral indentation by Li et al. [8]. Niknejad et al. [9] investigated the folding process in the hexagon cross-section tubes subjected to axial loading, using a theoretical model, numerical analysis and experimental method. Then, they theoretically presented a theoretical model of deformation for polyurethane foam during the folding process in foam-filled square tubes [10].

The present paper's objective is to compare the derived relations by Reddy and Reid [2] and Nemat-Alla [6] with the experimental results that obtained from flattening tests of brazen tubes with different geometrical properties and tracing stress-strain diagram of tube material, using the lateral compression tests and neglecting the strain hardening effects.n order of effect.

II. Theory

Reddy and Reid [2] derived a theoretical relation to predict the distance between the two equal and opposite forces on the curved portion of a quadrant of the tube (see Fig. 1) and hence, they calculated the moment arm that responsible for the maximum moments caused by these forces, as below:

$$A = \frac{D}{2} \cdot [1 - (\frac{d}{D})^2]^{1/2} \qquad (1)$$

where D is tube diameter and δ is lateral deflection of tube. From this relation it is obvious that A is independent of the tube length.

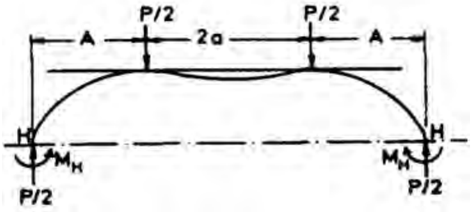

Fig. 1. The moment arm that responsible for the maximum moments caused by lateral forces [2]

Nemat-Alla [6] predicted the following relation to predict elastic modulus (E) of tube material, using the experimental results of flattening process:

$$E = \frac{24 \cdot b \cdot P_e \cdot r_0^3}{d_e \cdot t_o^3} \cdot (\frac{p}{8} - \frac{1}{p}) \qquad (2)$$

In the above equation, r0 and t0 are initial outer radius and thickness of the circular tube, respectively and P_e is the lateral force during the flattening process in elastic zone. $\beta=1/L$ in case of plane stress condition and L is the tube length. Nemat-Alla [6] introduced the following relation to calculate yield stress of tube material, based on the lateral compression test:

$$s_y = \frac{a \cdot P_{cr} \cdot R}{t_0^2 \cdot L} \qquad (3)$$

where R is inner radius of tube. The collapse load P_{cr} can be obtained by the intersection of the forward and backward extensions of elastic and plastic parts of the curve as shown in Fig. 2.

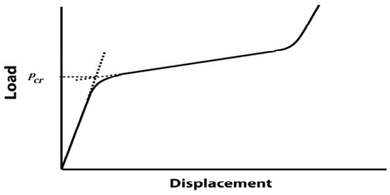

Fig. 2. Load–displacement curve from the tube lateral compression test [6]

The constant parameter α equals one in case of short tubes, length not greater than a few thicknesses, and α equals 0.866 if tube length is not less than one diameter of the compressed tube.

III. Experiment

All the lateral compression tests were performed by an Instron testing machine with loading rate of 10 mm/min. Six groups of circular cross-section tubes with different geometries were prepared to use in lateral compression tests between two rigid plates. Table 1 gives the specifications of specimens.

Table 1

Geometrical properties of specimens

Part No.	D (mm)	t (mm)	L (mm)
E-01	18	1	15
E-02	20	1	20
E-03	28	0.5	15
E-04	30	1	60
E-05	40	1	40
E-06	50	1	50

In this table outer diameter, thickness and length of tbes are denoted as D, t and L. All the specimens were prepared from the brazen tubes. The tensile yield stress and elastic modulus of the tube material are 504.4 MPa and 110 GPa, respectively.

IV. Results and Discussion

Experiments show that all the circular tubes do not show the same physical behavior during the flattening process and there are different shapes for the cross sections of tubes after the lateral compression tests. Figs. 3 to 5 show the different forms of the compressed tube cross sections. Eq. 1 only can be used when deflection form of tubes is like Fig. 3.

Fig. 3. Moment arm in tubes with t=1mm and D between 18 to 40 mm

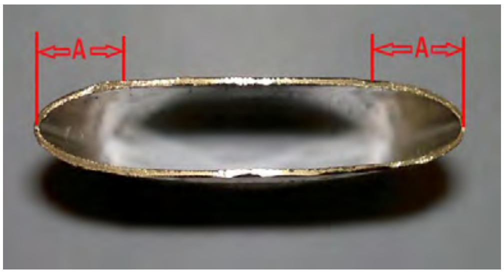

Fig. 4. Moment arm in tubes with t=0.5 mm

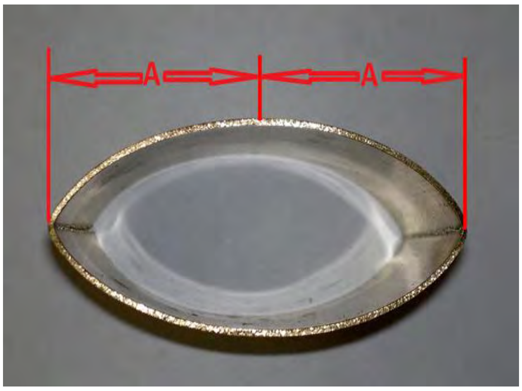

Fig. 5. Moment arm in tubes with D that is more than 40 mm

As obtained by experiments, the deflection form in thinner specimens and the specimens with larger diameters is different from Fig. 3. This is shown in Fig. 4 and Fig. 5, respectively. Experimental results show that by increasing the diameter of tubes, the difference of deflection form from Fig. 3 increases.

Table 2 gives the theoretical and experimental results which are obtained from Eq. 1 and lateral tests, respectively and the error percentages of predicted values by Eq. 1.

Table 2

Comparison of experiments
and theoretical results that obtained by Eq. 1

Part No.	Theory	Experiment	Error percentage
E-01	5.4	5.2	3.85
E-02	6	5.7	5.26
E-03	8.4	9.7	13.40
E-04	9	9.6	6.25
E-05	12	13.7	12.41
E-06	15	44	65.91

From Table 2 this is obvious that the error percentage increases by reduction of wall-thickness and increment of tubes diameter. The error percentages of computed magnitudes for tubes with larger diameters are so big and it is resulted that Eq. 1 can not be used for the specimens with large diameters.

Table 3 and Table 4 give the theoretical yield stress and elastic modulus of tubes material which obtained from Eq. 3 and Eq. 2, respectively, and the corresponding experimental values and error percentages of theoretical predictions.

Table 3

Comparison of experiments
and theoretical yield stress that obtained BY EQ. 3

Specimens	Experiment (MPa)	Theory (Mpa)	Error (%)
E-01	504.4	417.65	17.20
E-02	504.4	420.79	16.58
E-03	504.4	319.46	36.67
E-04	504.4	432.28	14.30
E-05	504.4	497.51	1.37

Table 4

Comparison of experiments
and theoretical elastic module that obtained BY EQ. 2

Specimens	Experiment (GPa)	Theory (GPa)	Error (%)
E-01	110	74.68	32.11
E-02	110	85.25	22.50
E-03	110	63.43	42.34
E-04	110	100.28	8.84
E-05	110	114.9	4.45

Based on the values of yield stress and elastic modulus, the stress-strain diagrams of tubes material can be sketched, considering no strain hardening effects.

Fig. 6 shows the stress-strain diagrams of brass that are obtained by Eq. 2 and Eq. 3 and comparison of them with the experimental diagram that is obtained from uniaxial tensile test on a dumbbell shape specimen. According to the figure, it is resulted that error of predicted stress-strain diagrams increases by decreasing the diameter and wall thickness of tubes. Thus, the stress-strain diagram of tubes material can be obtained and sketched based on the flattening test on circular tubes with larger diameters.

Conclusion

A relation of Reddy and Reid [2] which gives the produced moment arm in circular tubes subjected to lateral load is employed. Results that attained by this relation compared with flattening tests which carried out on six groups of brazen tubes between two rigid plates. Comparison of the experimental results with the theoretical predictions shows that large errors happen when tubes with larger diameters and thinner wall thicknesses are examined. Then, two relations introduced by Nemat-Alla [6] which gives elastic modulus and yield stress of material of tubes from flattening tests were investigated. Stress-strain diagrams of experimented specimens by neglecting the strain hardening effects were sketched from these two relations and compared with the corresponding experimental diagram that showed a logical correlation. Results show that decrement of diameter and wall thickness cause increment of errors

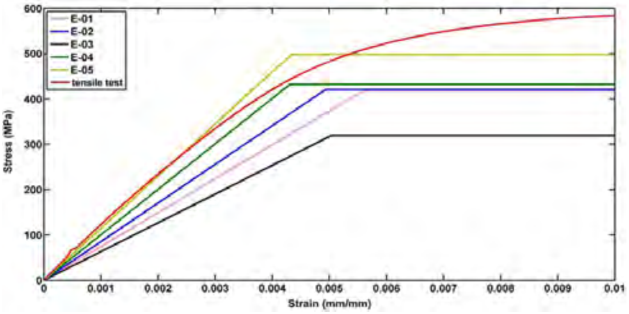

Fig.6 Comparison of the stress-strain diagrams of specimens that obtained with Eq. 2 and Eq. 3 and that obtained by tensile test

References

[1] P. B. Johns, "A symmetrical condensed node for the TLM method," IEEE Trans. Microwave Theory Tech., vol. MTT-35, pp.370-377, Apr. 1997.

[1] J. L. Yu, J. R. Li, S. S. Hu, "Strain-rate effect and micro-structural optimization of cellular metals," Mechanics of Materials, vol. 38, pp.160-170, 2006.

[2] T. Yella Reddy, S. R. Reid, "Phenomena associated with the crushing of metal tubes between rigid plates," International Journal of Solids Structures, vol. 16, pp.545-562, 1980.

[3] N. K. Gupta, Atul Khullar, "Collapse load analysis of square and rectangular tubes subjected to transverse in-plane loading," Thin-Walled Structures, vol. 21, pp.345-358, 1995.

[4] A. H. England, P. W. Gregory, "Finite lateral compression of an elastic-plastic fiber-reinforced tube: loading solutions," J. Mech. Phys. Solids., vol. 35, 1998.

[5] M. Zeinoddini, G. A. R. Parke, J. E. Harding, "Axially pre-loaded steel tubes subjected to lateral impacts: an experimental study," International Journal of Impact Engineering, vol. 27, pp.669-690, 2002.

[6] M. Nemat-Alla, "Reproducing hoop stress–strain behavior for tubular material using lateral compression test," International Journal of Mechanical Sciences, vol. 45, pp.605-621, 2003.

[7] O. Calme, D. Bigaud, P. Hamelin, "3D braided composite rings under lateral compression," Composites Science and Technology, vol. 65, pp.95-106, 2005.

[8] S. Li, S. R. Reid, P. D. Soden, M. J. Hinton, "Modelling transverse cracking damage in thin, filament-wound tubes subjected to lateral indentation followed by internal pressure," International Journal of Mechanical Sciences, vol. 47, pp.621-646, 2005.

[9] A. Niknejad, G. H. Liaghat, H. Moslemi Naeini, A. H. Behravesh, "A theoretical formula for predicting the instantaneous folding force of the first fold in a single cell hexagonal honeycomb under axial loading," Proc. IMechE Part C: J Mech Eng Sci, vol. 224, pp.2308-2315, 2010.

[10] A. Niknejad, G. H. Liaghat, H. Moslemi Naeini, A. H. Behravesh, "Theoretical and experimental studies of the instantaneous folding force of the polyurethane foam-filled square honeycombs," Mater. Des., vol. 32, pp.69-75, 2011.